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Combined Impact of Biodiesel and Exhaust Gas Recirculation on NOx Emissions in Di Diesel Engines

B.Jothithirumal and E.Jamesgunasekaran

Department of Mechanical Engineering
Annamalai University
Annamalainagar - 608002, Tamilnadu, INDIA
{bjtmal&jamesgunasekaran}@gmail.com

Abstract

In Diesel engines, NOx formation is a highly temperature-dependent phenomenon and takes place when the temperature in the combustion chamber exceeds 2000K. Therefore, in order to reduce NOx emissions in the exhaust, it is necessary to keep peak combustion temperatures under control.

One simple way of reducing the NOx emission of a diesel engine is by late injection of fuel into the combustion chamber. This technique is effective but increases fuel consumption by 10-15%,which necessitates the use of more effective NOx reduction techniques like exhaust gas recirculation (EGR).Re-circulating part of the exhaust gas helps in reducing NOx, but appreciable particulate emissions are observed at high loads, hence there is a trade-off between NOx and smoke emission. To get maximum benefit from this trade-off, a particulate trap may be used to reduce the amount of unburnt particulates in turn reduce the particulate emission also.

An experimental investigation was conducted to observe the effect of exhaust gas re-circulation on the exhaust gas temperature. The experimental setup for the proposed experiments was developed on a two-cylinder, direct injection, air-cooled, compression ignition engine. A matrix of experiments was conducted for observing the effect of different quantities of EGR on exhaust gas temperature.

Keyword – NO_x, EGR, Biodiesel, Injection pressure, and Crank angle.

1. Introduction

Over recent years, stringent emission legislations have been imposed on NOx, smoke and particulate emissions from automotive diesel engines world wide. Diesel engines are typically characterized by low fuel consumption and very low CO emissions. However, the NOx emissions from diesel engines still remain high.

Hence, in order to meet the environmental legislations, it is highly desirable to reduce the amount of NOx in the exhaust gas. Even though diesel engine exhaust has less carbon monoxide (CO) and hydrocarbon (HC) than gasoline engine exhaust, it contains considerable amount of particulate matter (PM) and oxide of nitrogen (NOx).

1.1. Mechanism of NOx formation

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A major hurdle in understanding the mechanism of formation and controlling its emission is that combustion is highly heterogeneous and transient in diesel engines.While NO and NO_2 are lumped togetheras NOx , there are some distinctive differences between these two pollutants. NO iscolourless andodourless gas, while NO_2 is a reddish brown gas with pungent odour. Both gases are considered toxic, but NO_2 hasa level of toxicity 5 times greater than that of NO. Although NO_2 is largely formed from oxidation of NO, attention has been given on how NO can be controlled before and after combustion (Levendis et al 1994)

NO formation is the oxidation of the nitrogen present in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process. The principal reactions governing the formation of NO from molecular nitrogen are,

$N_2 + O$ -----------------> $NO + N$

$N + O_2$---------------------> $NO + O$

$N + OH$---------------> $NO + H$

Chemical equilibrium consideration indicates that for burnt gases at typical flame temperatures, NO_2/NO ratios should be negligibly small. While experimental data show that this is true for spark ignition engines, in diesels, NO_2 can be 10 to 30% of total exhaust emissions of oxides of nitrogen. A plausible mechanism for the persistence of NO_2 is as follows. NO formed in the flame zone can be rapidly converted to NO_2 via reactions such as

$NO + HO_2$ ------------------> $NO_2 + OH$

Subsequently, conversion of this NO_2 to NO occurs via

$NO_2 + O$ -----------------> $NO + {}_2O$

Unless the NO_2 formed in the flame is quenched by mixing with cooler fluid.

The local atomic oxygen concentration depends on molecular oxygen concentration as well as local temperatures. Formation of NOx is almost absent at temperatures below 2000K. Hence any technique, that can keep the instantaneous local temperature in the combustion chamber below 2000K, will be able to reduce NOx formation.

1.2. EGR technique for NOx reduction

EGR is a useful technique for reducing NOx formation in the combustion chamber. Exhaust consists of CO_2,N_2 and water vapours mainly. When a part of this exhaust gas is re-circulated to the cylinder, it acts as diluents to the combusting mixture. This also reduces the O_2 concentration in the combustion chamber. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber,

$$\%EGR = \frac{VolumeofEGR}{Total\,\mathrm{int}\,akech\arg e\,\mathrm{int}\,othecylinder} x100$$

Another way to define the EGR ratio is by the use of CO_2 concentration (Baert et al 1999),

$$EGR = \frac{[CO_2]_{\mathrm{int}ake} - [CO_2]_{ambient}}{[CO_2]_{exhaust} - [CO_2]_{ambient}}$$

Three popular explanations for the effect of EGR on NOx reduction are increased ignition delay, increased heat capacity and dilution of the intake charge with inert gases. The ignition delay hypothesis asserts that because EGR causes an increase in ignition delay, it has the same effect as retarding the injection timing. The heat capacity hypothesis states that the addition of the inert exhaust gas into the intake increases the heat capacity (specific heat) of the non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature. According to the dilution theory, the effect of EGR on NOx is caused by increasing amounts of inert gases inn the mixture, which reduces the adiabatic flame temperature (Pierpont et al 1995)

At high loads, it is difficult to employ EGR due to deterioration in diffusion combustion and this may result in an excessive increase in smoke and particulate emissions. At low loads, unburnt hydrocarbons contained in the EGR would possibly re-burn in the mixture, leading to lower unburnt fuel in the exhaust and thus improved brake thermal efficiency. Apart from this, hot EGR would raise the intake charge temperature, thereby influencing combustion and exhaust emissions.

With the use of EGR, there is a trade-off between reduction in NOx and increase in soot, CO and unburnt hydrocarbons. A large number of studies have been conducted to investigate this. It is indicated that for more than 50% EGR, particulate emissions increase significantly, therefore use of a particulate trap is recommended. The change in oxygen concentration causes change in the structure of the flame and hence changes the duration of combustion. It is suggested that flame temperature reduction is the most important factor influencing NO formation.

Fig.1 shows the reduction in NOx emission due to EGR at different loads. Implementation of EGR in diesel engines has problems like (a) increased soot emission,(b) introduction of particulate matter into the engine cylinders. When the engine components come into contact with high velocity soot particulates, particulate abrasion may occur. Sulphuric acid and condensed water in EGR also cause corrosion. Some studies have detected damage on the cylinder walls due to the reduction in the oil's lubrication capacity, which is hampered due to the mixing of soot carried with the particulate laden recirculated exhaust gas. This necessitates the use of an efficient particular trap (Mehta et al 1994)

Studies have shown that EGR coupled with a high collection- efficiency particulate trap, controls smoke, unburnt hydrocarbon and NOx emissions simultaneously. The particulate trap, however, needs to be regenerated since its pores get clogged by the trapped soot particles. Clogged soot traps increase backpressure to the engine exhaust, thus affecting engine performance also. These traps need to be regenerated from time using thermal or aerodynamic or electrostatic regeneration techniques. Other methods of reducing the particulate emission from diesel engines include multiple injections, supercharging and higher fuel injection pressure etc. The highest attention is currently being paid to two self-regenerating systems: fuel additive-supported regeneration by using cerium-or iron –based additives, and a continuous regeneration trap (CRT) using sulphur-free diesel fuel (Zelenka et al 1998).

During the last 20 years, plenty of research work has been done on EGR and its effects on the engine performance in terms of fuel efficiency, volumetric efficiency, power generated etc,. These studies have been carried out at various loads, engine speed and variable engine parameters like temperature and pressure, compression ratio etc.

2. Classification Of EGR Systems

Various EGR systems have been classified on the basis of EGR temperature, configuration and pressure.

2.1. Classification based on temperature

(i)Hot EGR: Exhaust gas is recirculated without being cooled, resulting in increased intake charge temperature.

(ii) Fully cooled EGR: Exhaust gas is fully cooled before mixing with fresh in take air using a water-cooled heat exchanger. In this case, the moisture present in the exhaust gas may condense and the resulting water droplets may cause undesirable effects inside the engine cylinder.

(iii)Partly cooled EGR : To avoid water condensation, the temperature of the exhaust gas is kept just above its dew point temperature.

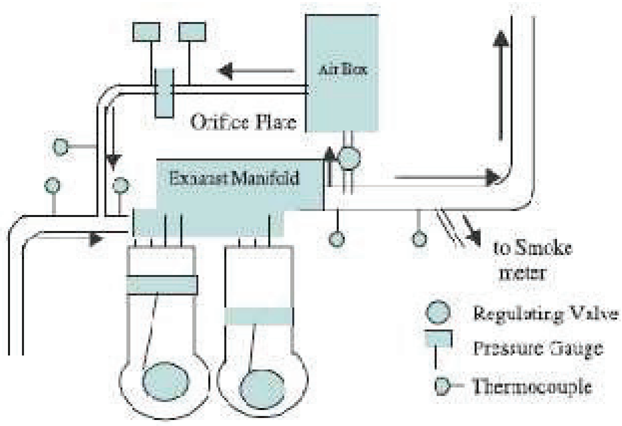

Fig.1 Experimental setup

2.2Classification based on configuration

(i) Long route system (LR): In an LR system the pressure drop across the air intake and the stagnation pressure in the exhaust gas stream make the EGR possible. The exhaust gas velocity creates a small stagnation pressure, which in combination with low pressure after the intake air, gives rise to a pressure difference to accomplish EGR across the entire torque /speed envelop of the engine.

(ii) Short route system (SR): These systems differed mainly in the method used to set up a positive pressure difference across the EGR circuit.

Another way of controlling the EGR-rate is to use variable nozzle turbine (VNT). Most of the VNT systems have single entrance, which reduce the efficiency of the system by exhaust pulse separation. Cooled EGR should be supplied effectively. Lundquist and others used a

Variable venture, in which EGR-injector was allowed to move axially, thus varying the critical area was used (Lundquist et al 2000).

2.3 Classification based on pressure

Two different routes for EGR, namely low-pressure and high pressure route systems may be used (Kohketsu et al 1997).

(i) Low pressure route system; the passage for EGR is provided from downstream of the turbine to the upstream side of the compressor.

It is found that by using the low pressure Route method, EGR is possible up to a high load region, with significant reduction in NOx. However, some problems occur, which influence durability, prohipitinary high compressor outlet temperature and intercooler clogging.

(ii) High pressure route system: The EGR is passed from upstream of the turbine to downstream of the compressor.

In the high pressure route EGR method, although EGR is possible in the high load regions, the excess air ratio decreases and fuel consumption increases remarkably.

III. EXEPERIMENTAL SETUP

Type	Vertical inline diesel engine
No – of cylinder	2
Bore	91.4 mm
Stroke	127mm
Displacement	1670 cc
Compression ratio	18.5:1
Cycle	4 stroke
Power	7.46 k w (10 H.P)
Speed	1500RPM
Orifice diameter	22 mm
Combustion system	Direct injection
Cooling system	Water cooling
Loading device	Swing field dynamometer

TABLE I
DIESEL ENGINE SPECIFICATION

The experiment is conducting in a four strokes, two cylinder, and constant speed compression ignition engine. The engine was Simpson make and water cooled, vertical, direct- injection. The engine is coupled with swing field dynamometer. The specification of the engine is given below.

At the rated speed (1500RPM), the engine develops approximately 7.46 KW (10 HP) power output.

The objective of developing this experimental test setup is to investigate and demonstrate the effects of various EGR rates and other engine parameters on exhaust emissions from the engine. A long route hot EGR system is chosen based on its merits. Several components of this EGR system have been designed and fabricated.

An air box is designed to measure the volumetric flow rate of intake air to the engine. It is mounted on the inlet pipe between the air filter and the inlet manifold of the engine as shown in fig 2. The air box dampens out the fluctuations of the intake air. A diaphragm is provided on the side of the air box for dampening out the local undulations effectively. The air box is fitted with an orifice (shown in fig 3) for volumetric flow rate measurement of air. A U-tube manometer is mounted across the orifice, to measure the pressure difference inside the air box and the atmosphere (Stearns et al 1951). The coefficient of discharge of the orifice is found experimentally to be 0.602.

3. Experimental program

The engine tests were conducted at constant speed of 1500 rpm at the maximum load range.Performance parameters such as break thermal efficiency, NOx, particulate matter, smoke density, CO, HC, CO2, and O2 were measured for the following different attempts.Normal engine setup (Fuel used-diesel).Engine equipped with exhaust gas recirculation system Engine with exhaust gas recirculation in different loads followed by 20% load with 25, 50, 75,100 percentage of EGR openings40% load with 25, 50, and 75,100Percentage of EGR openings60 % load with 25, 50, 75,100 percentage of EGR openings80% load with 25, 50, 75,100 percentage of EGR openings.100% load with 25, 50, 75,100 percentage of EGR openings

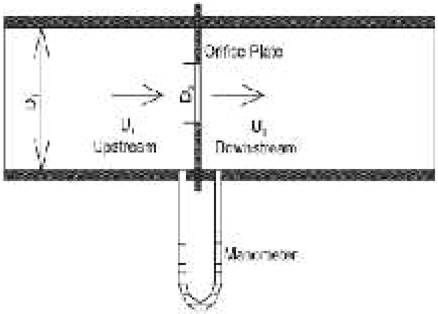

Fig. 2 EGR Flow test bench

Part of the exhaust is to be recirculated and put back to the combustion chamber along with the intake air. The quantity of this EGR is to be measured and controlled accurately hence a by-pass for the exhaust gas is provided along with the manually controlled EGR vale.

The exhaust gas comes out of the engine during the exhaust stroke at high pressure. It is pulsating in nature. It is desirable to remove these pulses in order to make the volumetric flow rate measurements of the recirculating gas possible. For this purpose, another smaller air box with a diaphragm is installed in the EGR route. An orifice meter is designed and installed to measure the volumetric flow rate of the EGR.

The detailed schematic line drawing of the experimental EGR system is shown in fig 2. A u-tube manometer is mounted across the orifice in order to measure the EGR flow rate. Suitable instrumentation is provided to acquire useful data from various locations. Thermocouples are provided at the intake manifold, exhaust manifold and various points along the EGR route.

The smoke density was observed by using the AVL smoke meter. The amount of particulate mater emitted was found by passing the exhaust gases through a glass filter paper placed in High volume sampler (HVAS) for time durations of one minute. The oxides of nitrogen were analyzed using an exhaust gas analyzer (EGA).

. The pressure difference across the orifice is used to calculate the EGR rate. . A matrix of test conditions is used to investigate the effect of EGR on exhaust gas temperature.

4. Results and Discussions

The engine parameters such as brake thermal efficiency (BTE), smoke density, oxides of nitrogen (NOx), particulate matter, carbon monoxide (CO), hydro carbon (HC), carbon-di-oxide (CO_2) and oxygen (O_2) are presented for various percentages of EGR Valve openings.

A. Brake thermal efficiency

From the figure, 3 the brake thermal efficiency was slightly higher in maximum percentage EGR valve opening for all load conditions.

Load-80%, IP-240Kg/cm2, IT-24ºBTDC

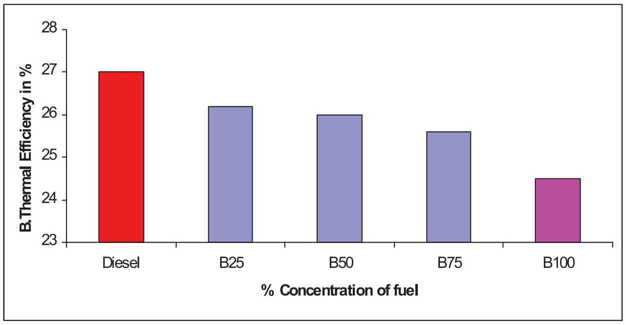

Fig. 3 B.T.EVs% concentration of fuel

B. Oxides of Nitrogen(NOx)

From the figure, 4 the smoke density is comparatively less in 25 percentage EGR valve opening in all load conditions.

Load-80%, IP-240Kg/cm2, IT-24ºBTDC

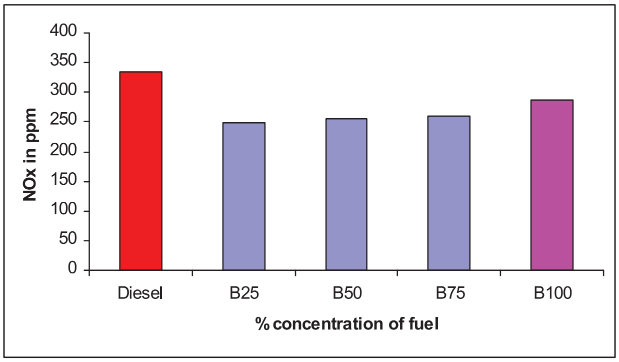

Fig. 4 NOxVs% concentration of fuel

C. Smoke Density

From the figure, 5 particulate matters are kept on increasing from zero percentage to maximum percentage valve opening in all load conditions.

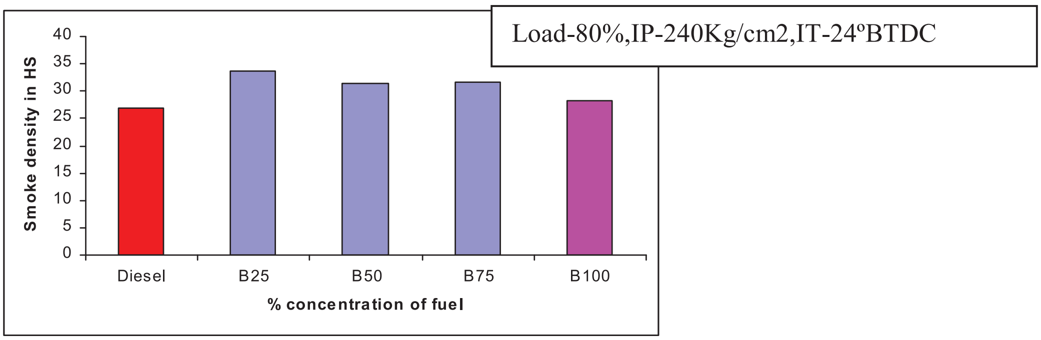

Fig. 5 smoke density Vs% concentration of fuel

D. Hydro Carbins (HC)

From the figure, 6 the oxides of nitrogen are relatively low in 25 percentage EGR valve opening for all load condition.

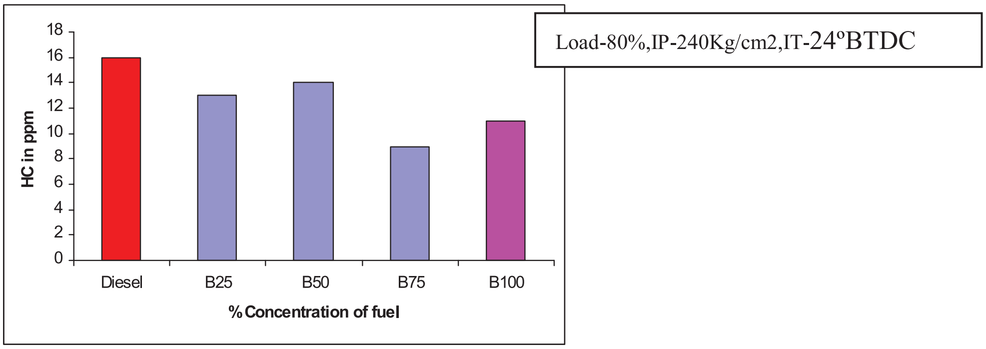

Fig. 6 HCVs% concentration of fuel

From fig. 7 the hydro carbons are drastically increase when EGR is implemented for all load conditions.

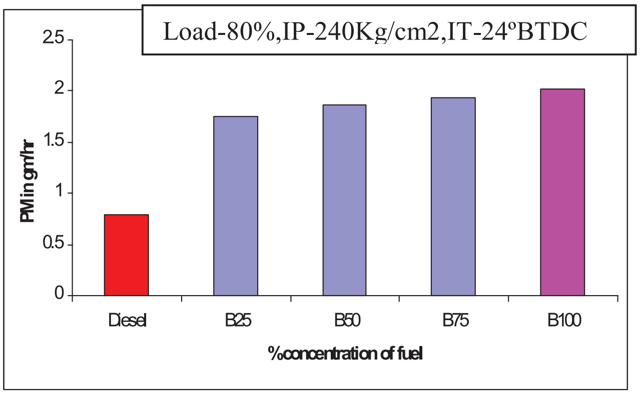

Fig. 7 PM Vs% concentration of fuel

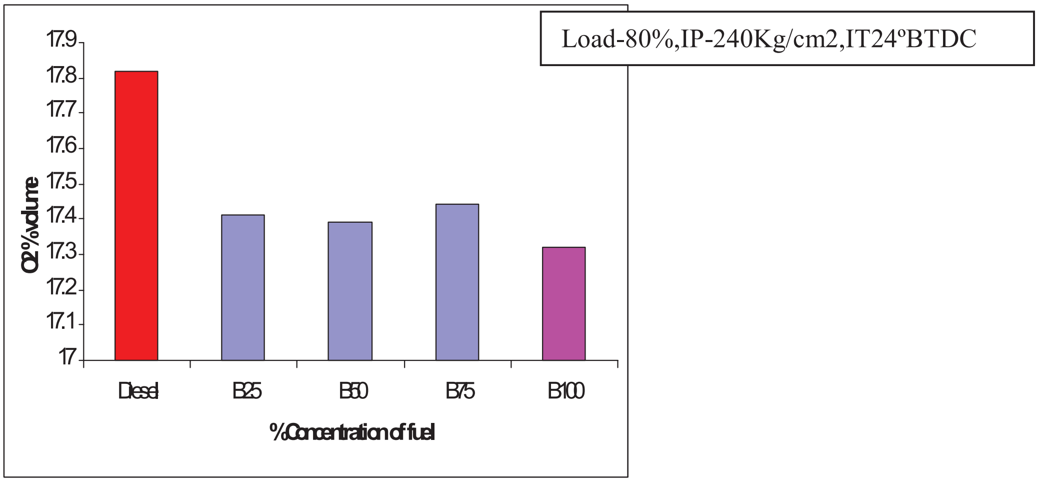

Fig.8 O_2Vs % concentration of fuel

5 Conclusion

The significant conclusion arrived from the experimental investigation are summarized. In this present work, maximum percentage valve opening of exhaust gas recirculation system shows reduction of NOx, CO and O2, when compare with normal diesel engine.

- ❖ The NOx level decreases with 25 percentage EGR valve opening with the neat diesel fuel for all loads.
- ❖ Smoke and particulate matter emission level increases with 25 percentage EGR valve opening adding with next diesel fuel.
- ❖ The Hydro carbon level increases with adding of 25 percentage EGR valve opening to the diesel fuel.
- ❖ There are no appreciable changes in break thermal efficiency in the implementation of the EGR.
- ❖ The optimum results for CO emission were obtained in the 25 percentage of EGR valve opening.
- ❖ The O_2 emission at 25 percentage EGR valve opening shows marginal reduction when compare to the sole fuel operation.

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